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(12) **United States Patent**
Sakai et al.

(10) **Patent No.: US 9,947,717 B2**
(45) **Date of Patent: Apr. 17, 2018**

(54) **LIGHT-EMITTING DEVICE HAVING LIGHT-EMITTING ELEMENTS AND ELECTRODE SPACED APART FROM THE LIGHT EMITTING ELEMENT**

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(73) Assignee: **Seoul Semiconductor Co., Ltd.**, Ansan-si (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 180 days.

(21) Appl. No.: **13/890,878**

(22) Filed: **May 9, 2013**

(65) **Prior Publication Data**

US 2013/0248900 A1 Sep. 26, 2013

Related U.S. Application Data

(60) Continuation of application No. 13/584,140, filed on Aug. 13, 2012, now abandoned, which is a (Continued)

(30) **Foreign Application Priority Data**

Aug. 29, 2002 (JP) 2002-249957

(51) **Int. Cl.**
H01L 33/32 (2010.01)
H01L 27/15 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01L 27/156*** (2013.01); ***H01L 27/15*** (2013.01); ***H01L 27/153*** (2013.01); ***H01L 33/08*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC H01L 33/32
(Continued)

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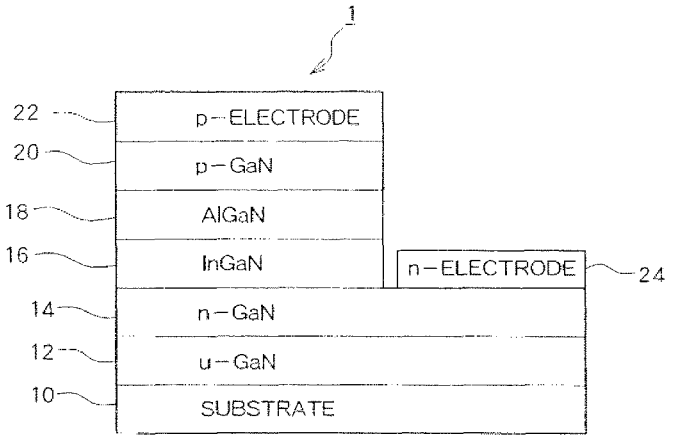
(57) **ABSTRACT**

A light-emitting device operating on a high drive voltage and a small drive current. LEDs (**1**) are two-dimensionally formed on an insulating substrate (**10**) of e.g., sapphire monolithically and connected in series to form an LED array. Two such LED arrays are connected to electrodes (**32**) in inverse parallel. Air-bridge wiring (**28**) is formed between the LEDs (**1**) and between the LEDs (**1**) and electrodes (**32**). The LED arrays are arranged zigzag to form a plurality of LEDs (**1**) to produce a high drive voltage and a small drive current. Two LED arrays are connected in inverse parallel, and therefore an AC power supply can be used as the power supply.

10 Claims, 19 Drawing Sheets



Related U.S. Application Data

continuation of application No. 12/958,947, filed on Dec. 2, 2010, now Pat. No. 8,735,918, which is a division of application No. 12/060,693, filed on Apr. 1, 2008, now Pat. No. 8,129,729, which is a continuation of application No. 10/525,998, filed as application No. PCT/JP03/10922 on Aug. 28, 2003, now Pat. No. 7,417,259.

(51) **Int. Cl.**

H01L 33/38	(2010.01)
H01L 33/62	(2010.01)
H01L 33/08	(2010.01)
H01L 33/42	(2010.01)

(52) **U.S. Cl.**

CPC ***H01L 33/32*** (2013.01); ***H01L 33/38*** (2013.01); ***H01L 33/42*** (2013.01); ***H01L 33/62*** (2013.01); *H01L 2224/24* (2013.01)

(58) **Field of Classification Search**

USPC 257/88, 93

See application file for complete search history.

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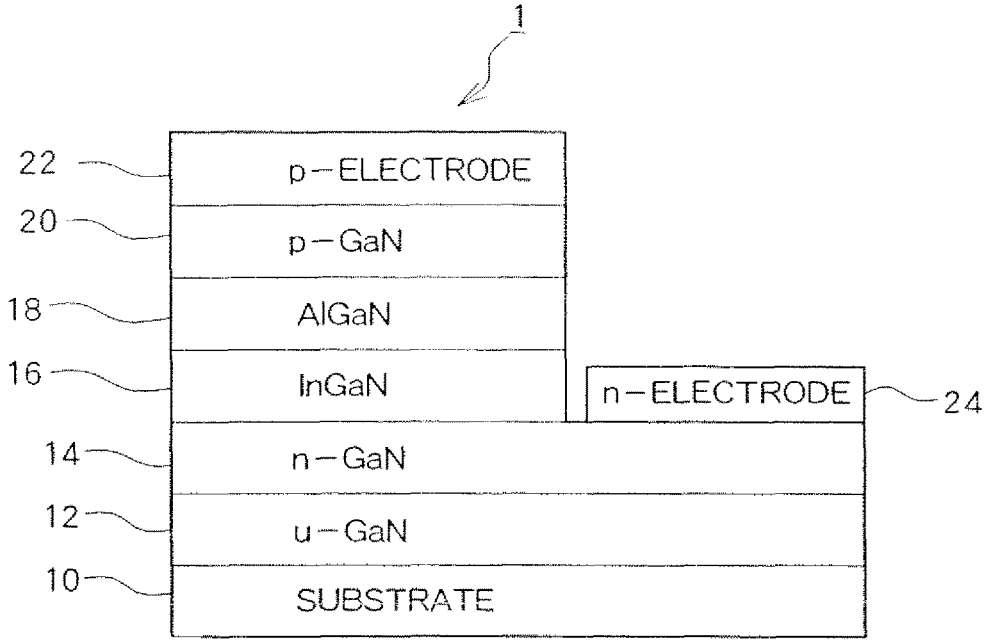
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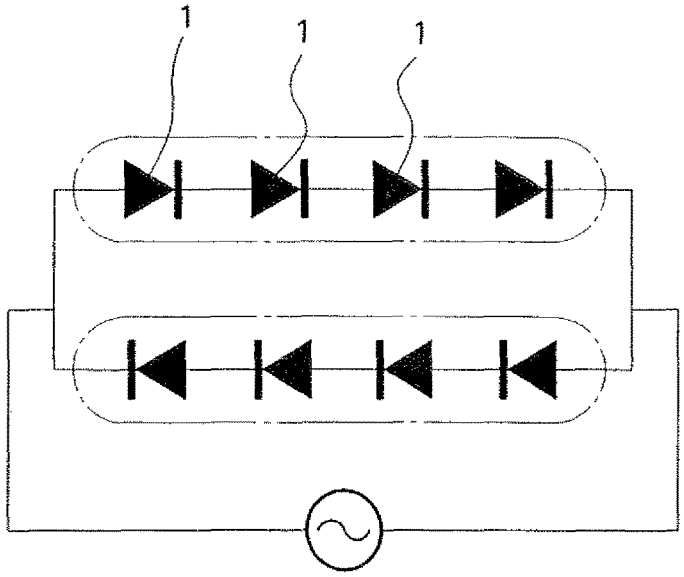
SUBSTRATE

Fig. 1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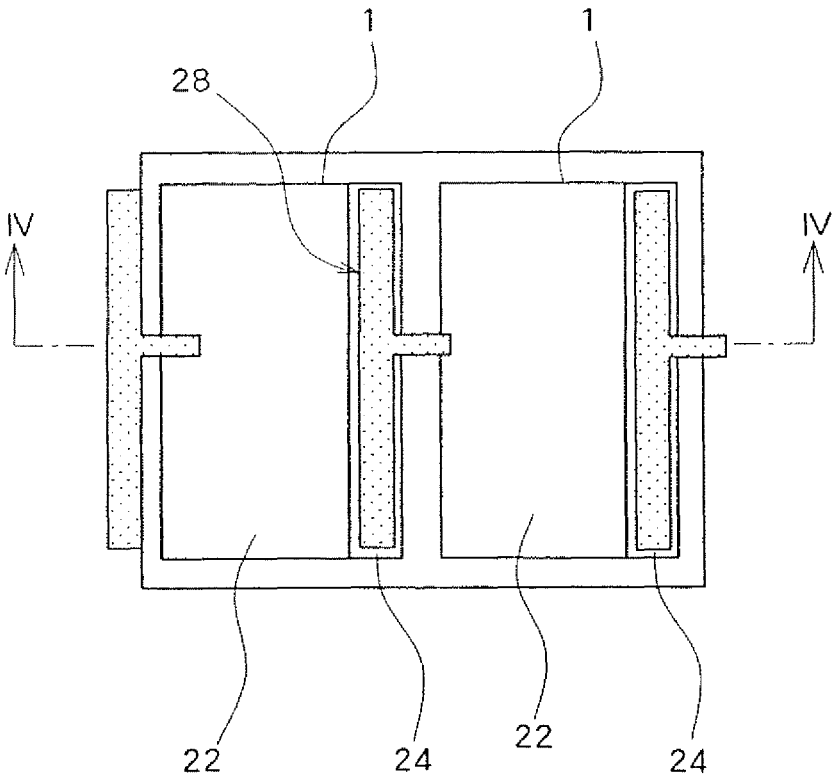

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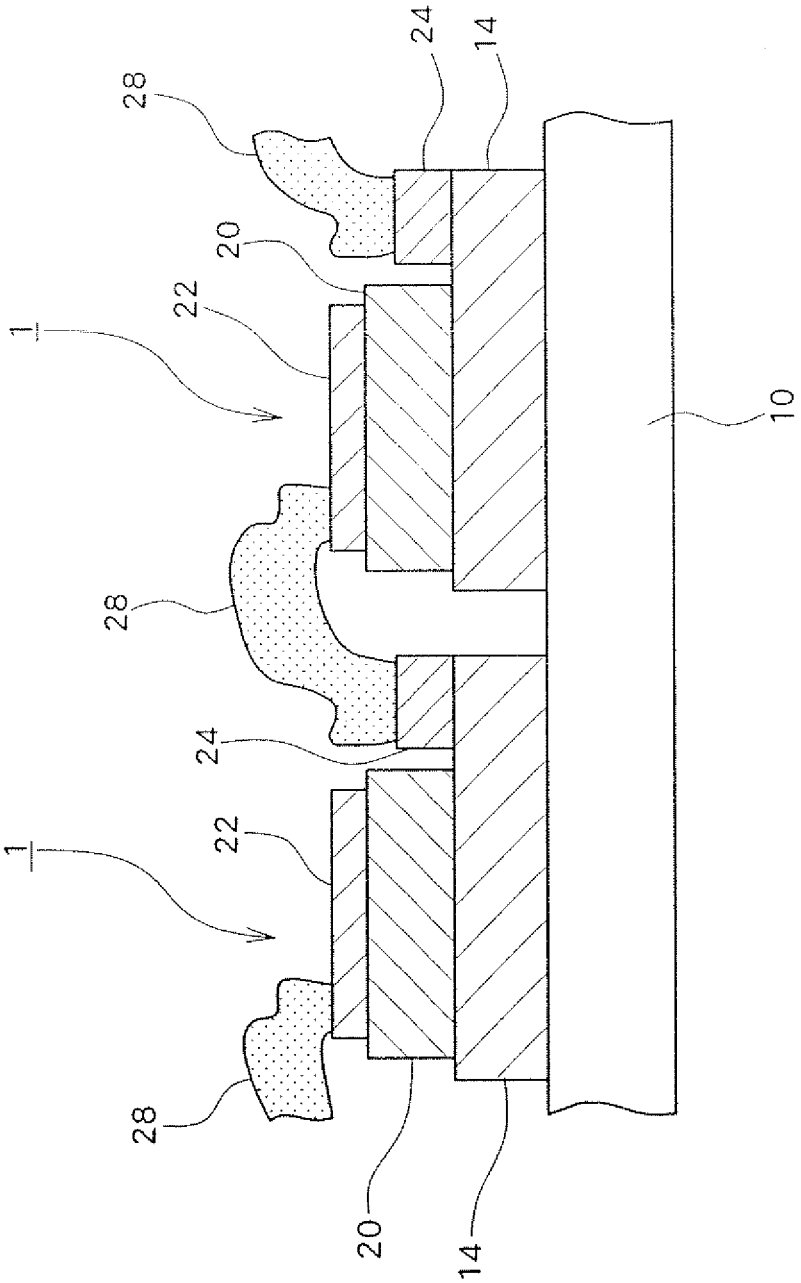

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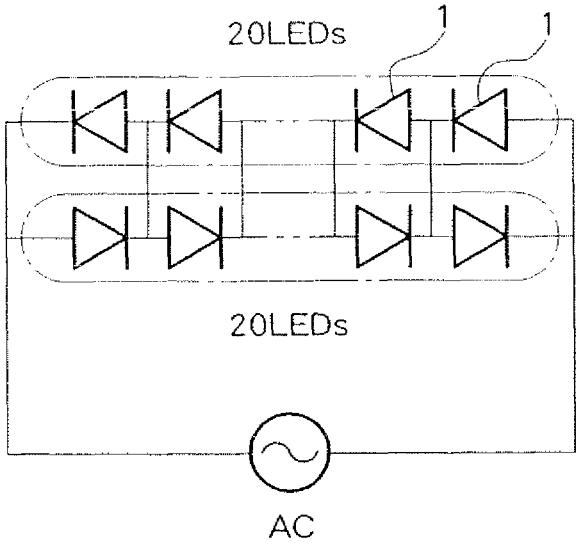

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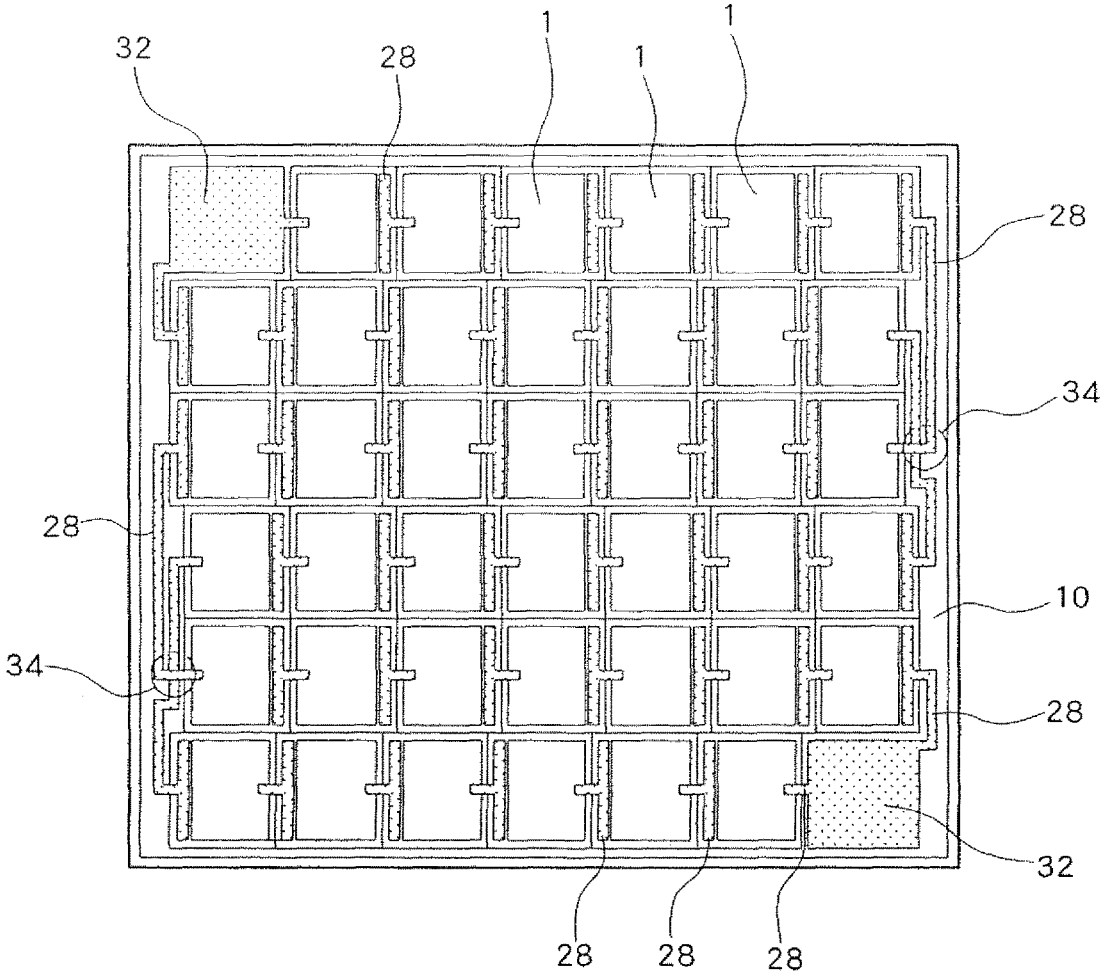

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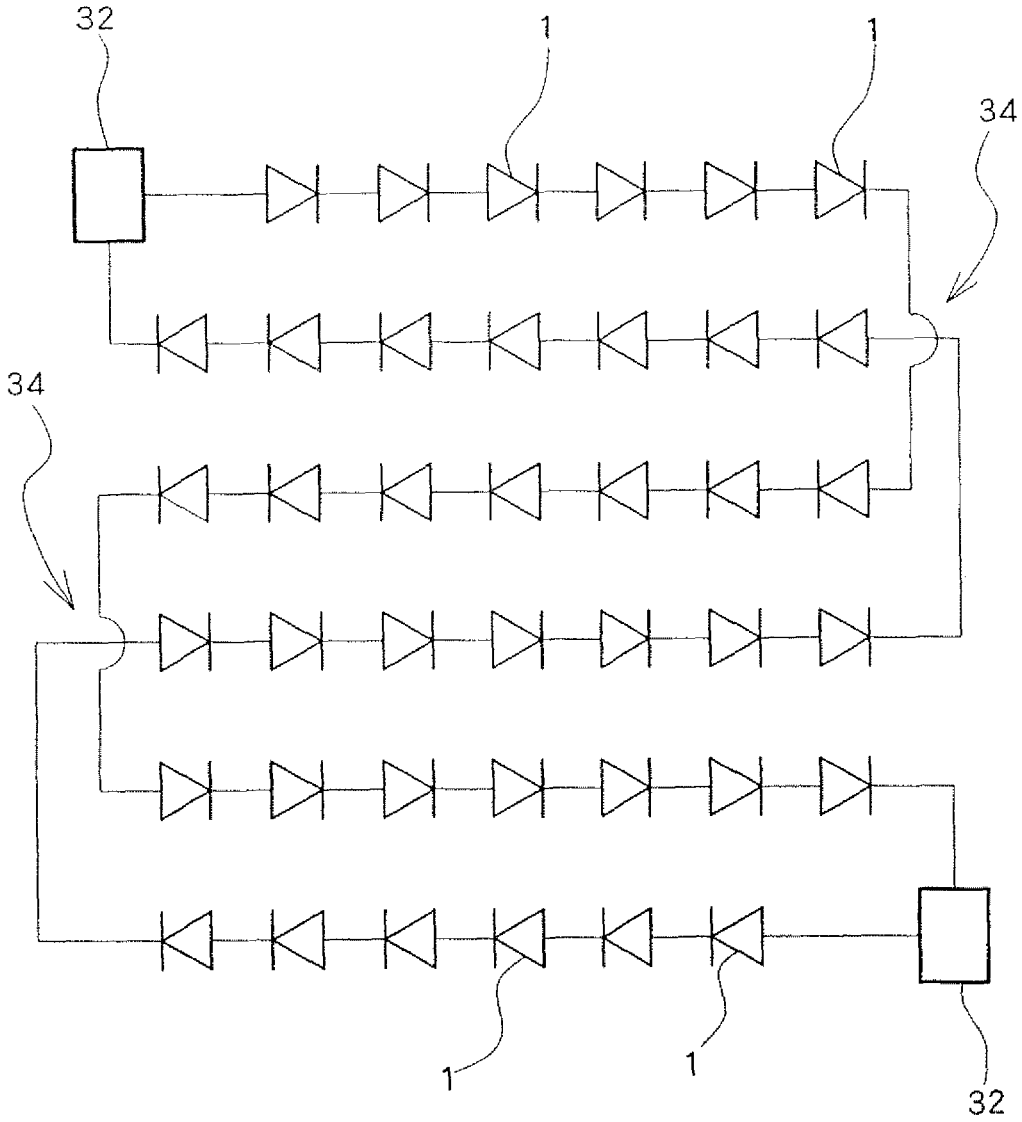

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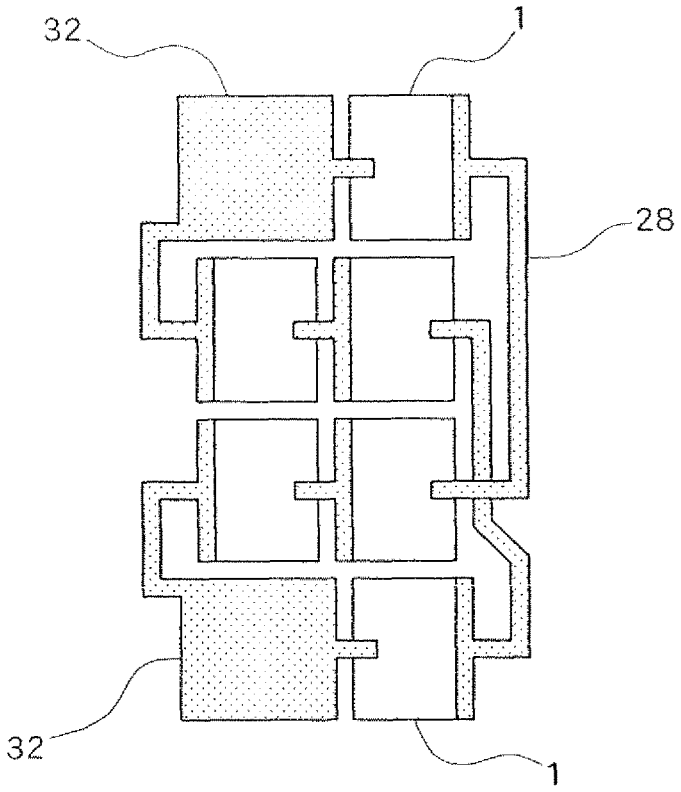

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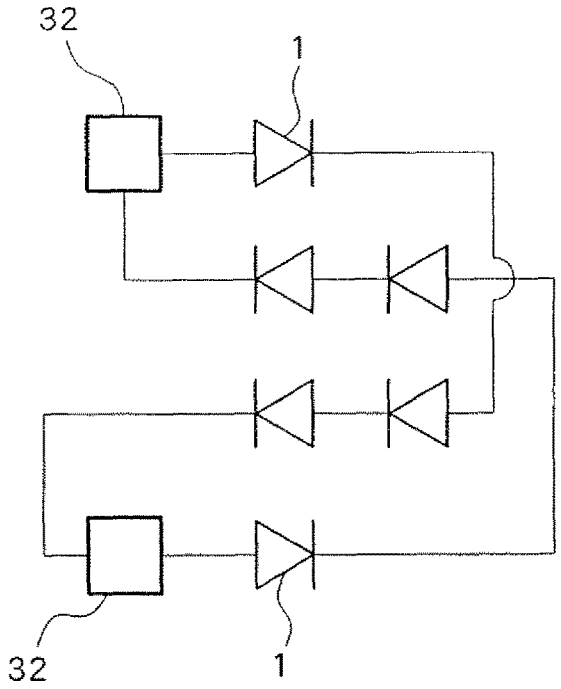

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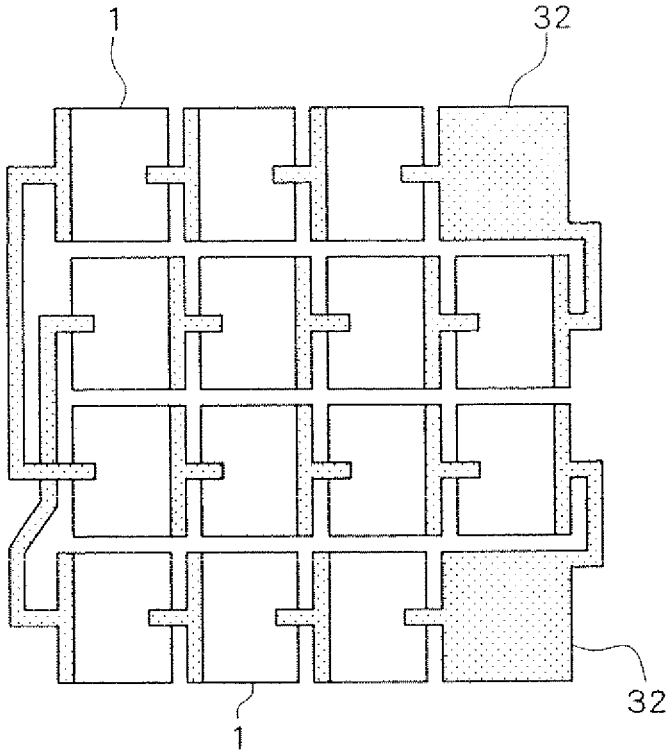

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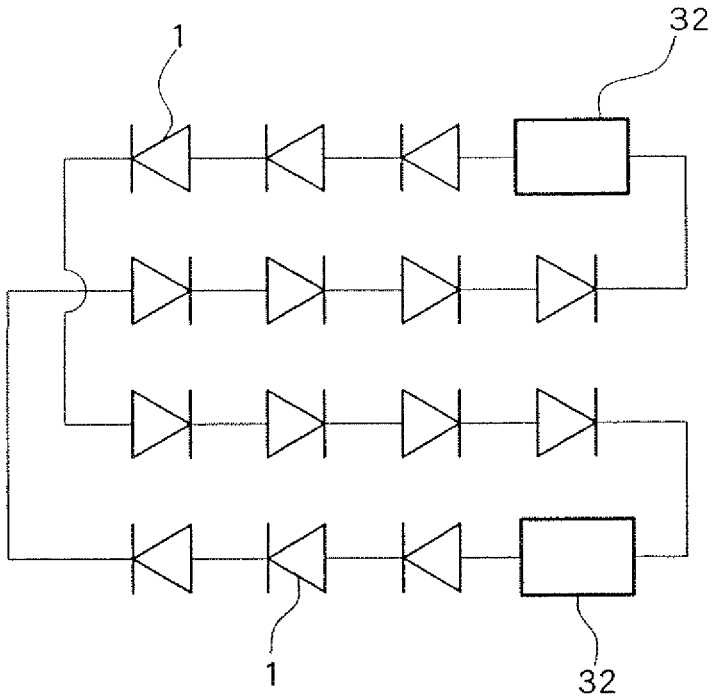

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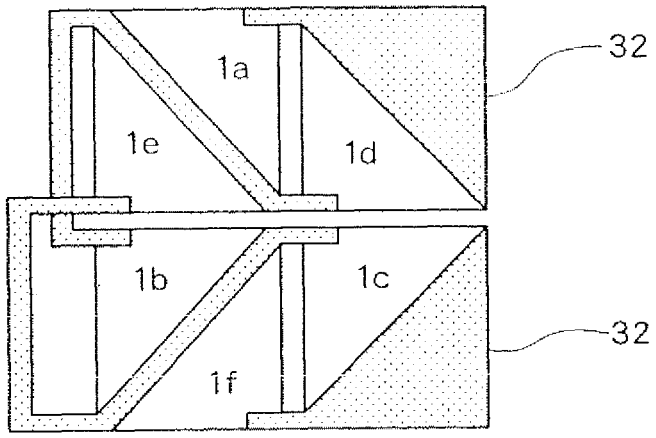

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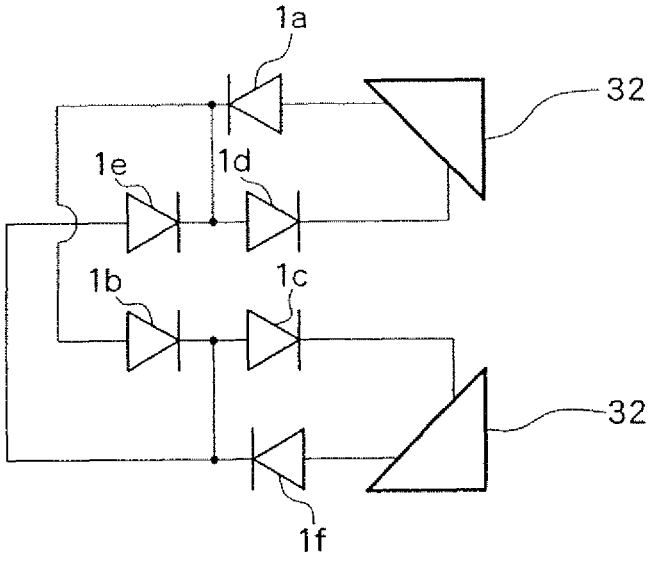

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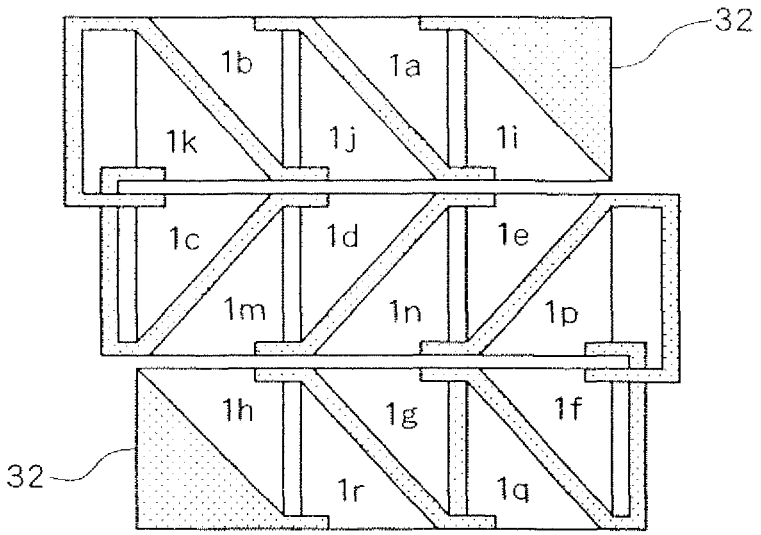
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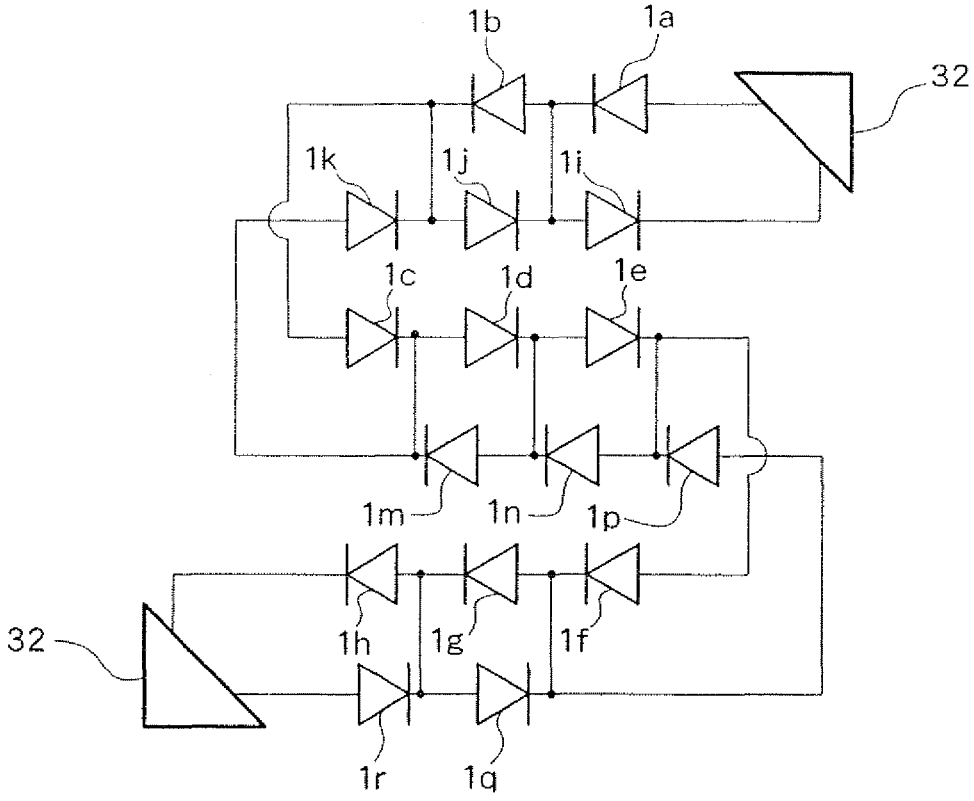
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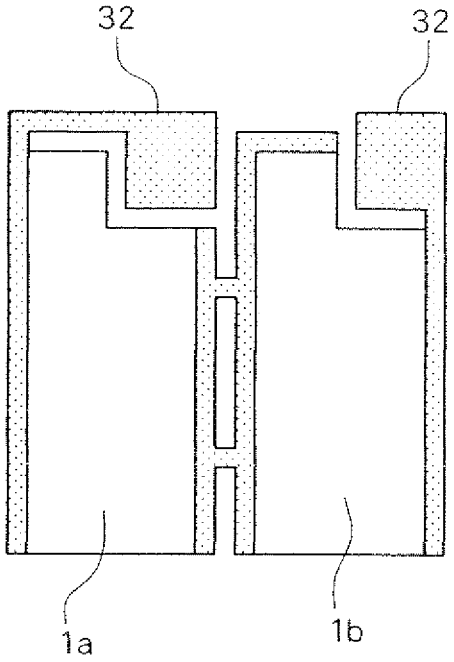
Fig. 15



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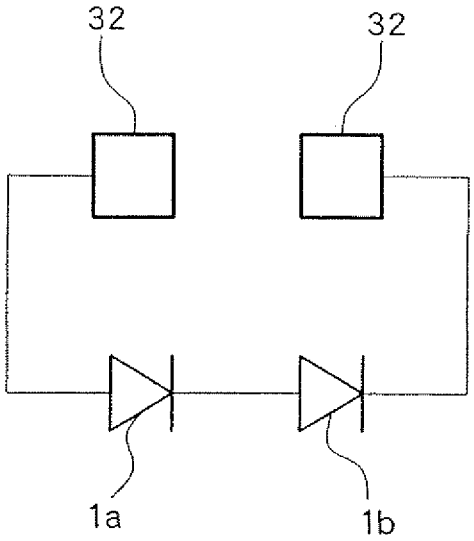

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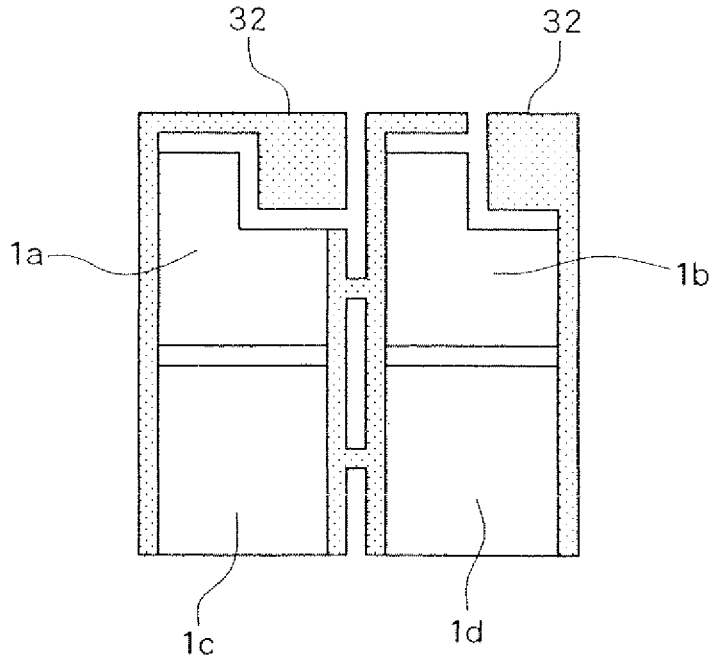

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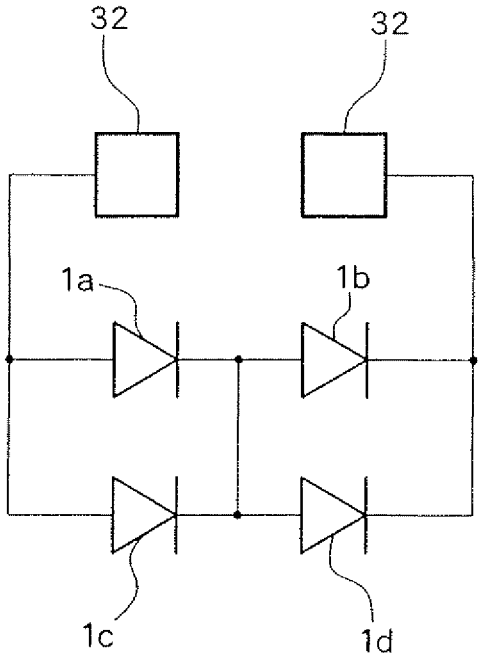

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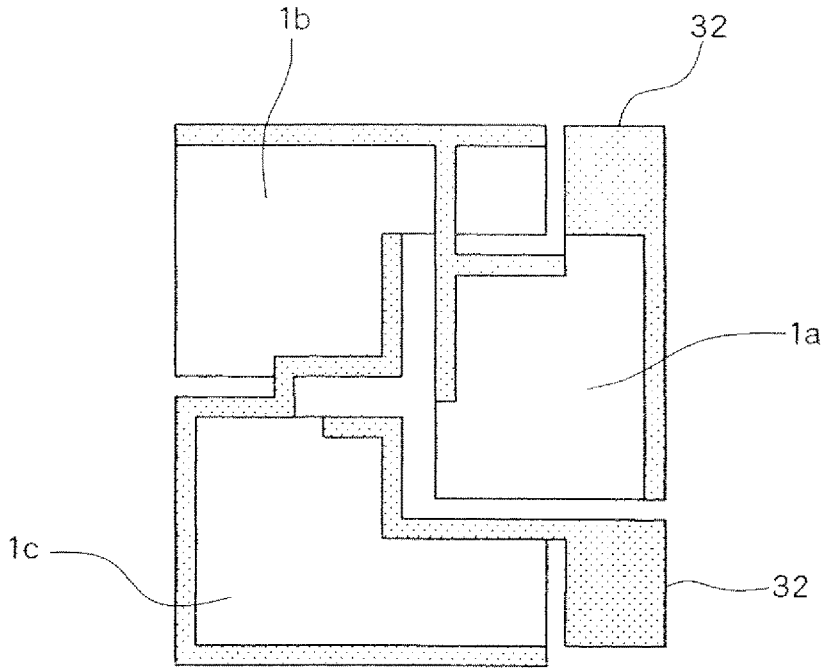

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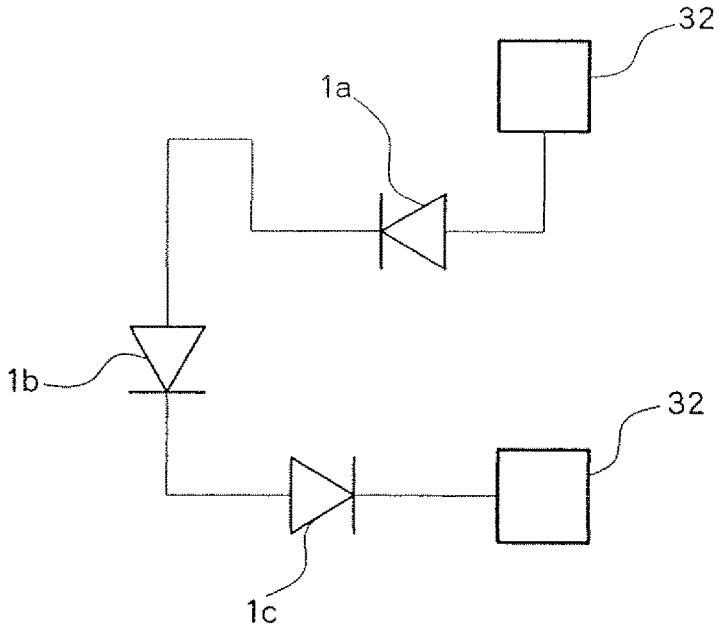

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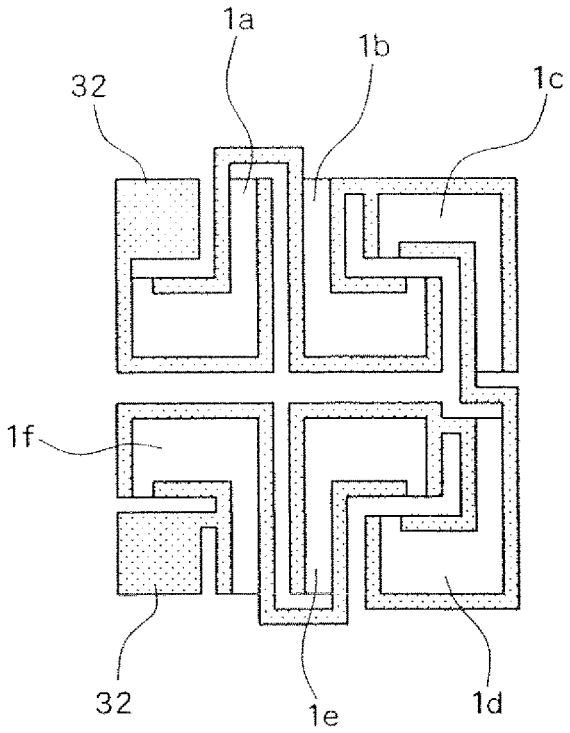

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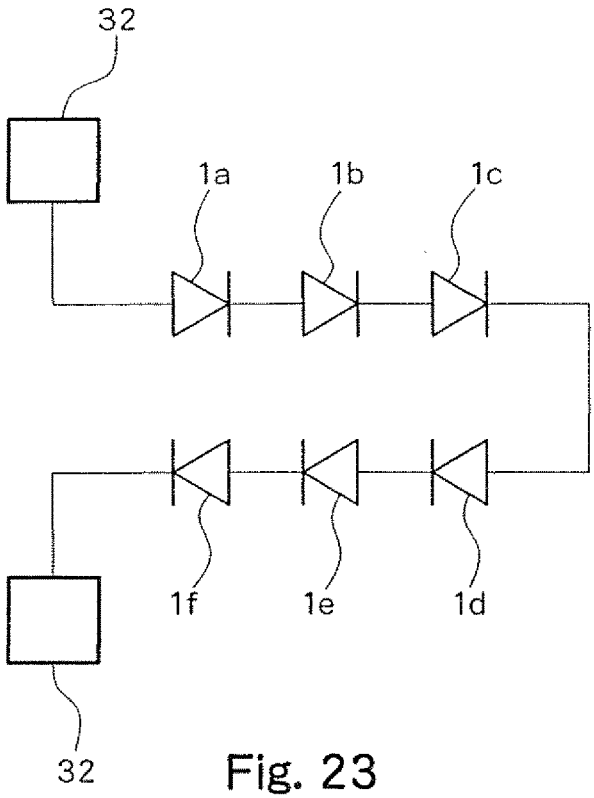

Fig. 23

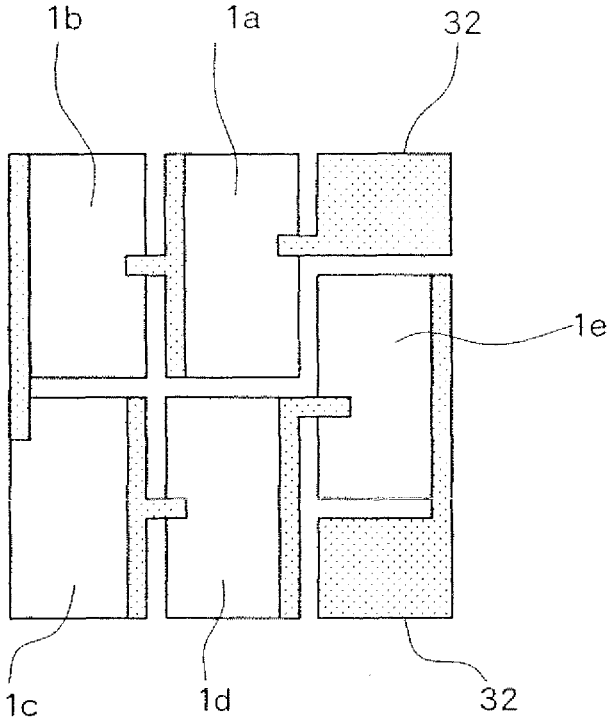

Fig. 24

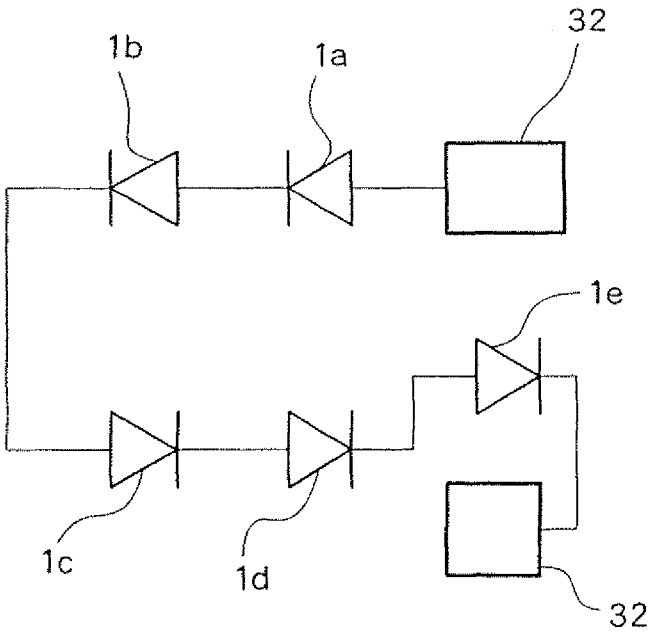

Fig. 25

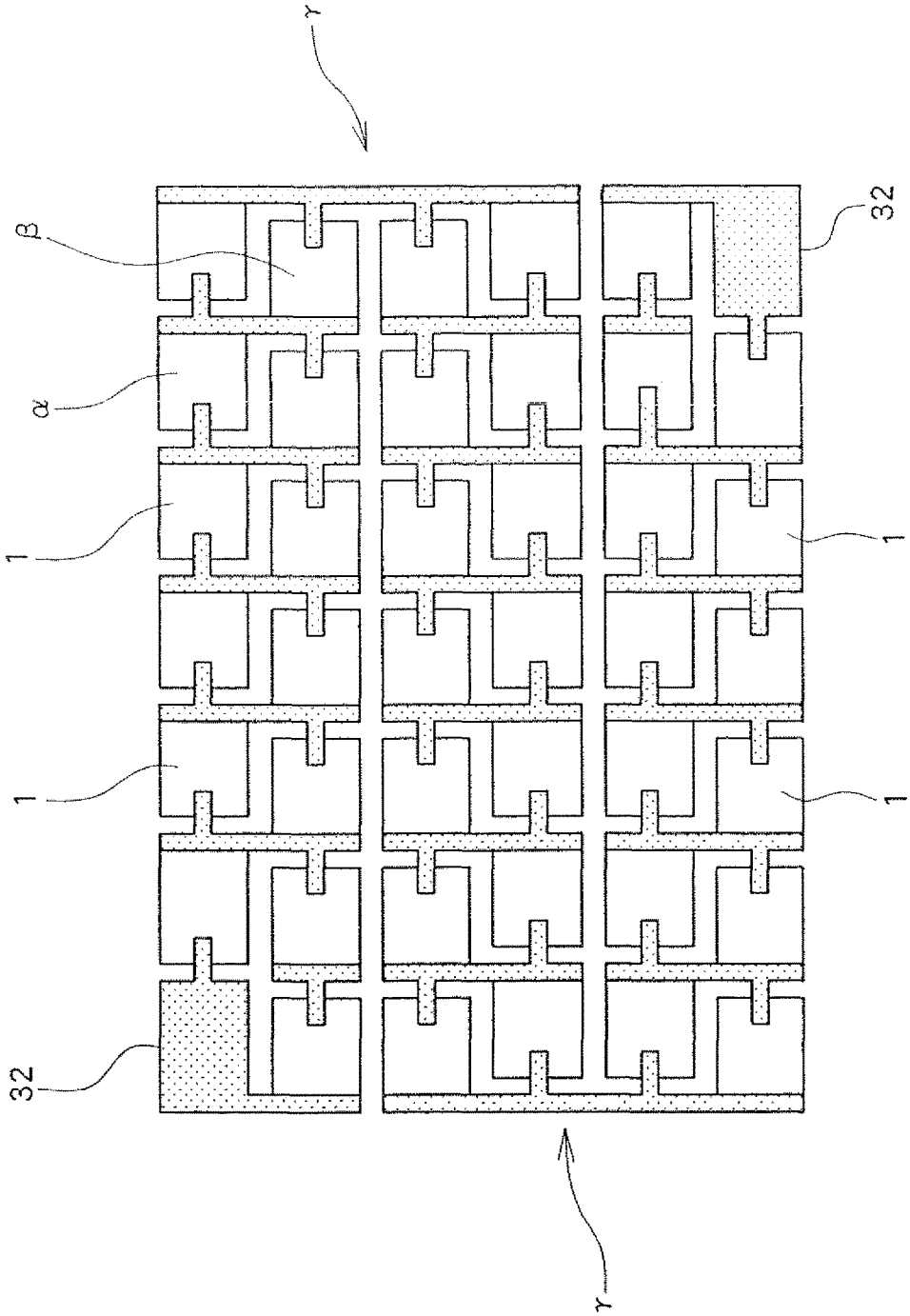

Fig. 26

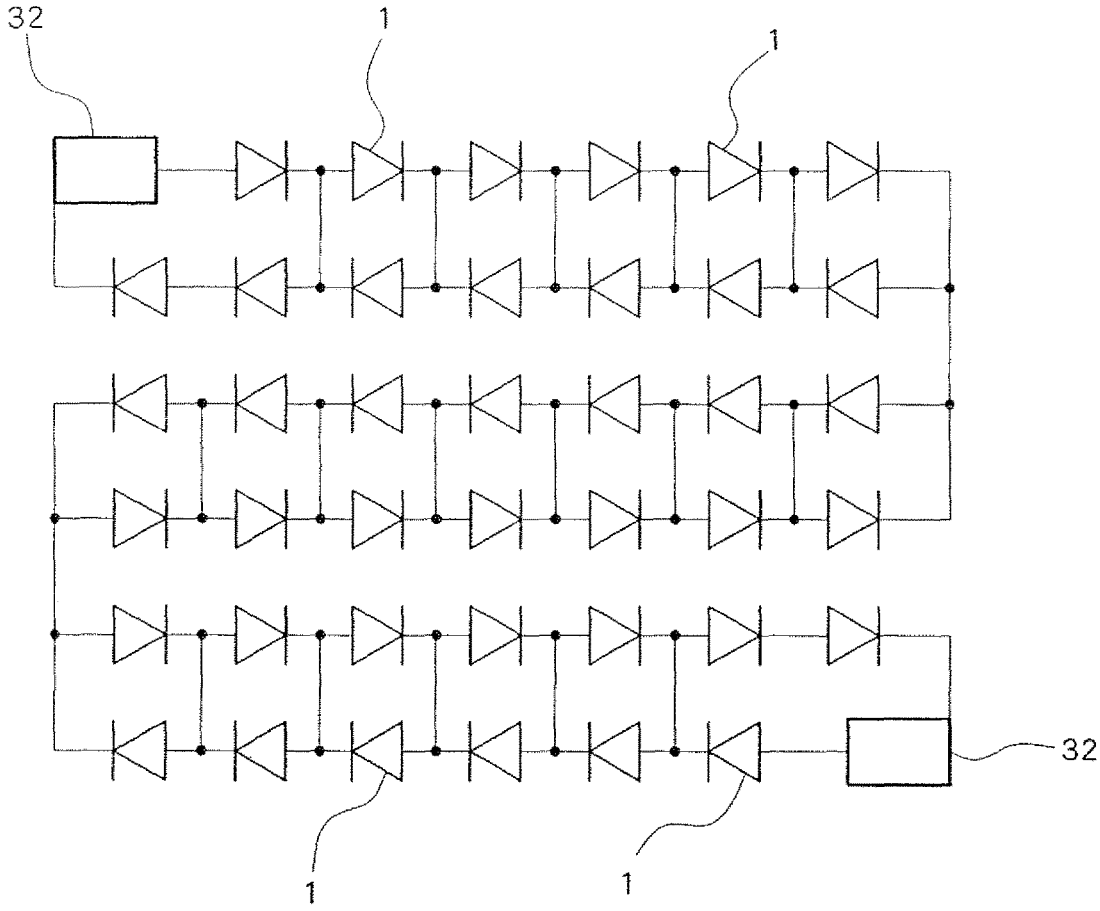

Fig. 27

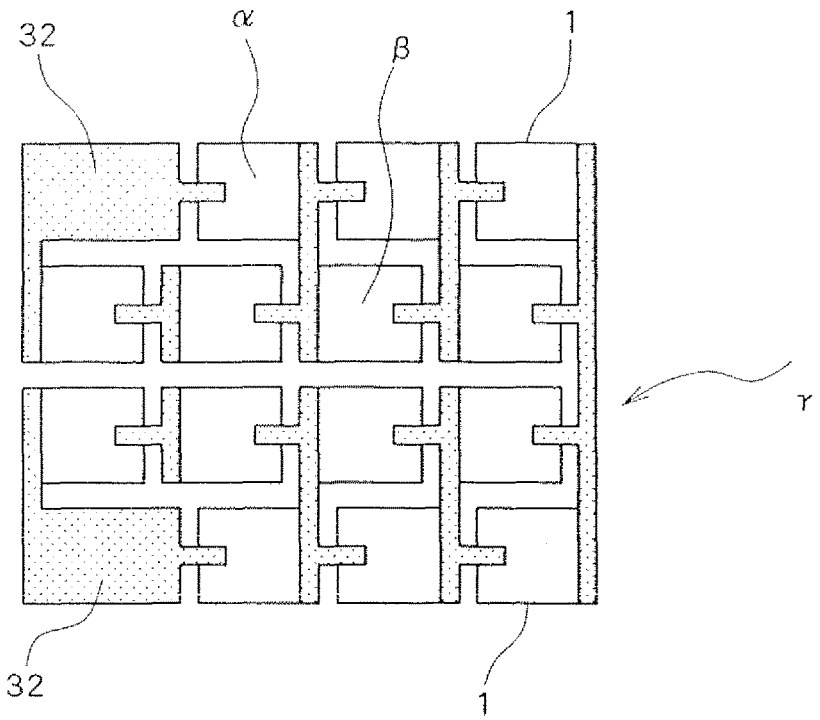

Fig. 28

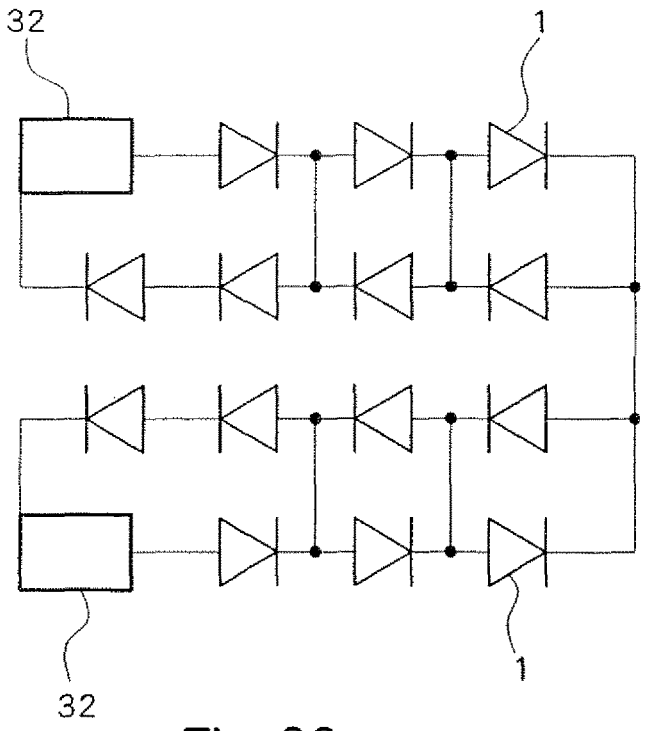

Fig. 29

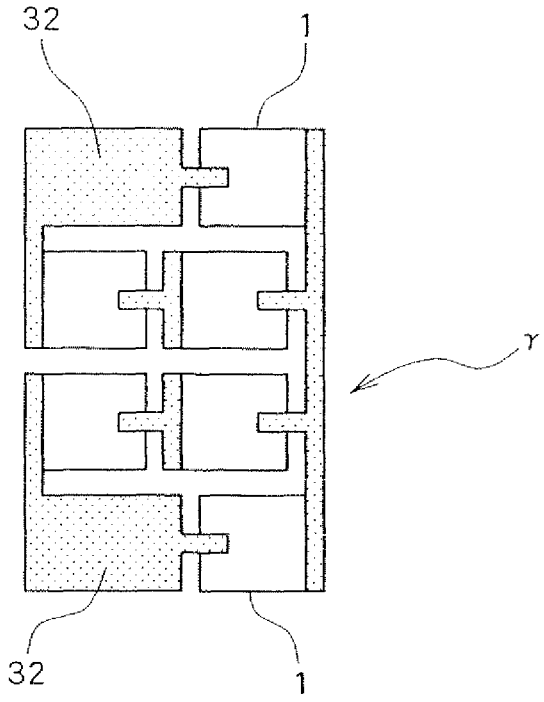

Fig. 30

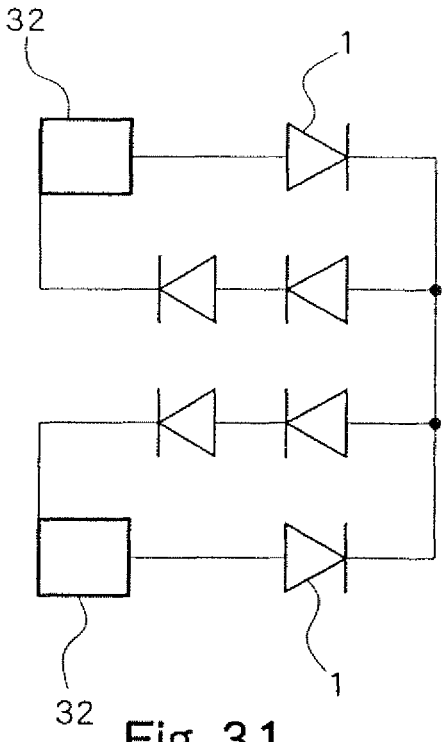

Fig. 31

LIGHT-EMITTING DEVICE HAVING LIGHT-EMITTING ELEMENTS AND ELECTRODE SPACED APART FROM THE LIGHT EMITTING ELEMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 13/584,140, filed on Aug. 13, 2012, which is a continuation of U.S. application Ser. No. 12/958,947, filed on Dec. 2, 2010, which is a divisional of U.S. application Ser. No. 12/060,693 filed on Apr. 1, 2008, issued as U.S. Pat. No. 8,129,729, which is a continuation of U.S. application Ser. No. 10/525,998, filed on Feb. 28, 2005, issued as U.S. Pat. No. 7,417,259, which is the National Stage of International Application No. PCT/JP03/10922, filed on Aug. 28, 2003, and claims priority from and the benefit of Japanese Patent Application No. 2002-249957, filed on Aug. 29, 2002, which are all hereby incorporated by reference for all purposes as if fully set forth herein.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a light emitting device in which a plurality of light emitting elements are formed on a substrate.

Discussion of the Background

When light emitting means such as a light emitting element (LED) is used for display or the like, typical usage conditions are approximately 1 V to 4 V for the drive voltage and approximately 20 mA for the drive current. With the recent development of short-wavelength LEDs which uses a GaN-based compound semiconductor and commercialization of solid light sources of full color, white color, etc., application of LEDs for illumination purposes has been considered. When an LED is used for illumination, there may be cases in which the LED is used under conditions other than the above-described conditions of 1 V-4 V of drive voltage and 20 mA of drive current. As a result, steps have been taken to enable a larger current to flow through the LED and to increase the light emission output. In order to flow a larger current, an area of a pn junction of the LED must be increased so that the current density is reduced.

When the LED is used as a light source for illumination, it is convenient to use an AC power supply and allow use with a drive voltage of 100 V or greater. In addition, if the same light emission output is to be obtained with supply of the same power, the power loss can be reduced by applying a high voltage while maintaining a low current value. In the LEDs of the related art, however, it is not always possible to sufficiently increase the drive voltage.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a light emitting device which can be operated with a high drive voltage.

According to one aspect of the present invention, there is provided a light emitting device wherein a plurality of GaN-based light emitting elements are formed on an insulating substrate and the plurality of light emitting elements are monolithically formed and connected in series.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the plurality of light emitting elements are arranged on the substrate in a two-dimensional pattern.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the plurality of light emitting elements are grouped into two groups and the two groups are connected between two electrodes in parallel so that the two groups are of opposite polarities.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the plurality of light emitting elements are connected by air bridge lines.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the plurality of light emitting elements are electrically separated by sapphire which is used as the substrate.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the plurality of light emitting elements are grouped into two groups having equal numbers of light emitting elements, an array of light emitting elements in each group are arranged in a zigzag pattern, and the two groups of light emitting element arrays are connected between two electrodes in parallel so that they are of opposite polarities. According to another aspect of the present invention, it is preferable that, in the light emitting device, the two groups of light emitting element arrays are arranged alternately.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the light emitting element and the electrode have a planar shape of approximate square or triangle.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the overall shape of the plurality of light emitting elements and the electrode is approximate square.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the electrode is an electrode for an alternate current power supply.

According to another aspect of the present invention, it is preferable that, in the light emitting device, the two groups of light emitting element arrays have a common n electrode.

In the present invention, a plurality of light emitting elements are monolithically formed, that is, formed on a same substrate, and are connected in series. With this structure, the present invention allows a high drive voltage. By connecting a plurality of light emitting elements along one direction, a DC drive is possible. By grouping the plurality of light emitting elements into two groups and connecting the two groups between electrodes such that the two groups of light emitting elements (light emitting element arrays) are of opposite polarities from each other, it is possible to also allow an AC drive. The numbers of elements in the groups may be the same or different.

Various methods are available for two-dimensionally placing or arranging a plurality of light emitting elements, and a method which minimizes an area occupied on the substrate is desirable. For example, by arranging the two groups of light emitting element arrays in zigzag pattern, that is, arranging a plurality of light emitting elements on a bent line and alternately arranging the light emitting element arrays, the substrate area can be efficiently utilized and a large number of light emitting elements can be connected. When the two light emitting element arrays are alternately positioned, a crossing portion of lines may occur. It is possible to effectively prevent short-circuiting at the crossing portion by connecting the light emitting elements by air bridge lines. The shapes of the light emitting elements and the electrodes is not limited. By forming the light emitting elements and the electrodes to have a planar shape of, for example, approximate square, the overall shape becomes an approximate square, which allows for the use of a standard

mounting structure. It is also possible to employ a shape other than the square, for example, a triangle, for the light emitting elements and the electrodes, to form an approximate square shape as an overall shape by combining the triangles, and, as a consequence, it is possible to use a standard mounting structure in a similar manner.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing a basic structure of a light emitting element (LED).

FIG. **2** is an equivalent circuit diagram of a light emitting device.

FIG. **3** is a plan view of two LEDs.

FIG. **4** is a cross-sectional view along a IV-IV line of FIG. **3**.

FIG. **5** is another equivalent circuit diagram of a light emitting device.

FIG. **6** is an explanatory diagram of a structure in which 40 LEDs are arranged in a two-dimensional pattern.

FIG. **7** is a circuit diagram of the structure shown in FIG. **6**.

FIG. **8** is an explanatory diagram of a structure in which 6 LEDs are arranged in a two-dimensional pattern.

FIG. **9** is a circuit diagram of the structure shown in FIG. **8**.

FIG. **10** is an explanatory diagram of a structure in which 14 LEDs are arranged in a two-dimensional pattern.

FIG. **11** is a circuit diagram of the structure shown in FIG. **10**.

FIG. **12** is an explanatory diagram of a structure in which 6 LEDs are arranged in a two-dimensional pattern.

FIG. **13** is a circuit diagram of the structure shown in FIG. **12**.

FIG. **14** is an explanatory diagram of a structure in which 16 LEDs are arranged in a two-dimensional pattern.

FIG. **15** is a circuit diagram of the structure shown in FIG. **14**.

FIG. **16** is an explanatory diagram of a structure comprising 2 LEDs.

FIG. **17** is a circuit diagram of the structure shown in FIG. **16**.

FIG. **18** is an explanatory diagram of a structure in which 4 LEDs are arranged in a two-dimensional pattern.

FIG. **19** is a circuit diagram of the structure shown in FIG. **18**.

FIG. **20** is an explanatory diagram of a structure in which 3 LEDs are arranged in a two-dimensional pattern.

FIG. **21** is a circuit diagram of the structure shown in FIG. **20**.

FIG. **22** is an explanatory diagram of a structure in which 6 LEDs are arranged in a two-dimensional pattern.

FIG. **23** is a circuit diagram of the structure shown in FIG. **22**.

FIG. **24** is an explanatory diagram of a structure in which 5 LEDs are arranged in a two-dimensional pattern.

FIG. **25** is a circuit diagram of the structure shown in FIG. **24**.

FIG. **26** is an explanatory diagram of another two-dimensional arrangement.

FIG. **27** is a circuit diagram of the structure shown in FIG. **26**.

FIG. **28** is an explanatory diagram of another two-dimensional arrangement.

FIG. **29** is a circuit diagram of the structure shown in FIG. **28**.

FIG. **30** is an explanatory diagram of another two-dimensional arrangement.

FIG. **31** is a circuit diagram of the structure shown in FIG. **30**.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

A preferred embodiment of the present invention will now be described referring to the drawings.

FIG. **1** shows a basic structure of an LED **1** which is a GaN-based compound semiconductor light emitting element of the present embodiment. The LED **1** has a structure in which a GaN layer **12**, an Si-doped n-type GaN layer **14**, an InGaN light emitting layer **16**, an AlGaN layer **18**, and a p-type GaN layer **20** are sequentially layered on a substrate **10**, a p electrode **22** is formed in contact with the p-type GaN layer **20**, and an n electrode **24** is formed in contact with the n-type GaN layer **14**.

The LED shown in FIG. **1** is manufactured through the following process. First, a sapphire c-plane substrate is thermally treated for 10 minutes in a hydrogen atmosphere at a temperature of 1100° C. in an MOCVD device. Then, the temperature is reduced to 500° C. and silane gas and ammonia gas are supplied for 100 seconds to form a discontinuous SiN film on the substrate **10**. This process is applied in order to reduce a dislocation density within the device and the SiN film is not shown in FIG. **1**. Next, trimethyl gallium and ammonia gas are supplied at the same temperature to grow a GaN layer to a thickness of 20 nm. The temperature is raised to 1050° C. and trimethyl gallium and ammonia gas are supplied again to grow an undoped GaN (u-GaN) layer **12** and an Si-doped n-type GaN layer **14** to a thickness of 2 μm each. Then, the temperature is reduced to approximately 700° C. and an InGaN light emitting layer **16** is grown to a thickness of 2 nm. A target composition is x=0.15, that is, $IN_{0.15}Ga_{0.85}N$. After the light emitting layer **16** is grown, the temperature is raised to 1000° C., an AlGaN hole injection layer **18** is grown, and a p-type GaN layer **20** is grown.

After the p-type GaN layer **20** is grown, the wafer is taken out of the MOCVD device and a Ni layer of 10 nm and a Au layer of 10 nm are sequentially vacuum-evaporated to form these layers on the surface of the grown layer. A thermal treatment is applied in a nitrogen gas atmosphere containing 5% oxygen at a temperature of 520° C. so that the metal film becomes a p-type transparent electrode **22**. After the transparent electrode is formed, a photoresist is applied over the entire surface and an etching process is applied for forming an n-type electrode using the photoresist as a mask. The depth of etching is, for example, approximately 600 nm. A Ti layer of 5 nm thickness and an Al layer of 5 nm thickness are formed above the n-type GaN layer **14** exposed by the etching process and a thermal treatment is applied in a nitrogen gas atmosphere at a temperature of 450° C. for 30 minutes to form an n-type electrode **24**. Finally, a rearside of the substrate **10** is ground to a thickness of 100 μm and chips are cut away and mounted to obtain the LED **1**.

In FIG. **1**, one GaN-based LED **1** is formed on a substrate **1**, but in the present embodiment, a plurality of LEDs **1** are monolithically formed on the substrate **10** in a two-dimensional array and the LEDs are connected to form the light emitting device (chip). Here, "monolithic" indicates that all elements are formed on one single substrate.

FIG. **2** is a diagram showing an equivalent circuit of the light emitting device. In FIG. **2**, the light emitting elements formed in the two-dimensional array are grouped into two

groups of same number of light emitting elements (in FIG. **2**, 4 light emitting elements). The LEDs **1** in each group are connected in series and the two groups of LED arrays are connected in parallel between electrodes (drive electrodes) such that the two groups are of opposite polarities. In this manner, by connecting the array of LEDs in series, it is possible to drive the LEDs **1** at a high voltage in which the drive voltage of each LED is added. Because the LED arrays are connected in parallel between the electrodes such that the LED arrays are of opposite polarities, even when an AC power supply is used as a power supply, one of the LED array always emits light in each period of the power supply, which allows an effective light emission.

FIG. **3** is a partial plan view of a plurality of LEDs monolithically formed on the substrate **10**. FIG. **4** is a diagram showing a IV-IV cross section of FIG. **3**. In FIG. **3**, a p electrode **22** and an n electrode **24** are formed on the upper surface of the LED **1** as shown in FIG. **1**. The p electrode **22** and the n electrode **24** of adjacent LEDs **1** are connected through an air bridge line **28** and a plurality of LEDs **1** are connected in series.

In FIG. **4**, the LEDs **1** are shown in a simple manner for explanation purposes. Specifically, only the n-GaN layer **14**, the p-GaN layer **20**, the p-electrode **22**, and the n-electrode **24** are shown. In real applications, the InGaN light emitting layer **16** is also present as shown in FIG. **1**. The air bridge line **28** connects from the p electrode **22** to the n electrode **24** through the air. In this manner, in contrast to a method of applying an insulating film on a surface of the element, forming electrodes on the insulating film, and electrically connecting the p electrode **22** and the n electrode **24**, it is possible to avoid the problem of degradation of the LEDs **1** as a result of thermal diffusion of elements forming the insulating material to the n layer and p layer from a line disconnection or insulating film, because it is no longer necessary to place the electrodes along the etching groove. The air bridge line **28** is also used for connecting between the LED **1** and the electrode which is not shown in FIG. **4**, in addition to the connection between the LEDs **1**.

In addition, as shown in FIG. **4**, the LEDs **1** must be independent and electrically insulated from each other. For this purpose, the LEDs **1** are separated on the sapphire substrate **10**. Because sapphire is an insulating material, it is possible to electrically separate the LEDs **1**. By using the sapphire substrate **10** as a resistive body for achieving an electrical separation between the LEDs, it is possible to electrically separate the LEDs in an easy and reliable manner.

As the light emitting element, it is also possible to employ an MIS in place of the LED having a pn junction.

FIG. **5** is a diagram showing another equivalent circuit of the light emitting device. In FIG. **5**, 20 LEDs **1** are connected in series to form one LED array and two such LED arrays (a total of 40 LEDs) are connected to a power supply in parallel. The drive voltage of the LED **1** is set to 5 V, and thus, the drive voltage of each LED array is 100 V. The two LED arrays are connected in parallel to the power supply such that the LED arrays are of opposite polarities, similar to FIG. **2**. Light is always emitted from one of the LED arrays, regardless of the polarity of the power supply.

FIG. **6** shows a specific structure of the two-dimensional array and corresponds to the equivalent circuit diagram of FIG. **2**. In FIG. **6**, a total of 40 LEDs **1** are formed on the sapphire substrate **10** which are grouped into two groups of 20 LEDs **1**. The groups of LEDs **1** are connected in series by the air bridges **28** to form two LED arrays. More specifically, all of the LEDs **1** has a square shape of the same size and same shape. A first LED array comprises, from the top line toward the bottom line, a line of 6 LEDs are arranged in a straight line, a line of 7 LEDs are arranged in a straight line, and a line of 7 LEDs are arranged in a straight line. The first row (6 LEDs) and the second row (7 LEDs) are formed facing opposite directions and the second row and the third row are formed facing opposite directions. The first row and the second row are separated from each other and the second row and the third row are separated from each other, because rows of the other LED array are alternately inserted, as will be described later. The rightmost LED **1** of the first row and the rightmost LED **1** of the second row are connected by an air bridge line **28** and the leftmost LED **1** of the second row and the leftmost LED **1** of the third row are connected by an air bridge line **28** to construct a zigzag arrangement. The leftmost LED **1** of the first row is connected to an electrode (pad) **32** formed on an upper left section of the substrate **10** by an air bridge line **28** and the rightmost LED **1** of the third row is connected to an electrode (pad) **32** formed on a lower right section of the substrate **10** by an air bridge line **28**. The two electrodes (pads) **32** have the same square shape as the LEDs **1**. The second LED array is alternately formed in the spaces of the first LED array. More specifically, in the second LED array, 7 LEDs, 7 LEDs, and 6 LEDs are formed on straight lines from the top to the bottom, the first row is formed between the first row and the second row of the first LED array, the second row is formed between the second row and the third row of the first LED array, and the third row is formed below the third row of the first LED array. The first row and the second row of the second LED array are formed facing opposite directions and the second row and the third row of the second LED array are formed facing opposite directions. The rightmost LED **1** of the first row is connected to the rightmost LED **1** of the second row by an air bridge line **28** and the leftmost LED **1** of the second row is connected to the leftmost LED **1** of the third row by an air bridge line **28** to construct a zigzag arrangement. The leftmost LED of the first row of the second LED array is connected to the electrode **32** formed on the upper left section of the substrate **10** by an air bridge line **28** and the rightmost LED **1** of the third row is connected to the electrode **32** formed on the lower right section of the substrate **10** by an air bridge line **28**. Polarities of the LED arrays with respect to the electrodes **32** are opposite from each other. The overall shape of the light emitting device (chip) is rectangular. It should also be noted that two electrodes **32** to which a power supply is supplied are formed in diagonally opposite positions of the rectangle and are spaced apart.

FIG. **7** is a circuit diagram of the circuit shown in FIG. **6**. It can be seen from this figure that each LED array is connected in series while bending in a zigzag pattern and two LED arrays have the zigzag shaped rows formed between the rows of the other LED array. By employing such a configuration, many LEDs **1** can be arranged on a small substrate **10**. In addition, because only two electrodes **32** are required for 40 LEDs **1**, the usage efficiency on the substrate **10** can be further improved. Moreover, when the LEDs **1** are individually formed in order to separate LEDs **1**, the wafer must be cut for separation, but, in the present embodiment, the separation between LEDs **1** can be achieved through etching, which allows for narrowing of a gap between the LEDs **1**. With this configuration, it is possible to further reduce the size of the sapphire substrate **10**. The separation between LEDs **1** is achieved by etching and removing regions other than the LEDs **1** to the point which reaches the substrate **10** by using photoresist, reactive

ion etching, and wet etching. Because the LED arrays alternately emit light, the light emission efficiency can be improved and heat discharging characteristic can also be improved. Moreover, by changing the number of LEDs **1** to be connected in series, the over all drive voltage can also be changed. In addition, by reducing the area of the LED **1**, it is possible to increase the drive voltage per LED. When 20 LEDs **1** are serially connected and are driven with a commercially available power supply (100 V, 60 Hz), a light emission power of approximately 150 mW can be obtained. The drive current in this case is approximately 20 mA.

As is clear from FIG. **7**, when two LED arrays are alternately arranged in a zigzag pattern, a crossing section **34** inevitably occurs in the air bridge line **28**. For example, when the first row and the second row of the second LED array are connected, this portion crosses the line portion for connecting the first row and the second row of the first LED array. However, the air bridge line **28** of the present embodiment is not adhered to the substrate **10** as described above and extends through the air, distanced from the substrate **10**. Because of this structure, short-circuiting due to contact of the air bridge lines **28** at the crossing section can be easily avoided. This is one advantage of using the air bridge line **28**. The air bridge line **28** is formed, for example, through the following processes. A photoresist is applied over the entire surface to a thickness of 2 μm and a post bake process is applied after a hole is opened in a shape of the air bridge line. Over this structure, a Ti layer of 10 nm and a Au layer of 10 nm are evaporated in this order through vacuum evaporation. A photoresist is again applied over the entire surface to a thickness of 2 μm and holes are opened in portions in which the air bridge lines are to be formed. Then, using Ti and Au as electrodes, Au is deposited over the entire surface of the electrodes to a thickness of 3-5 μm through ion plating (plating) in an electrolyte. Then, the sample is immersed in acetone, the photoresist is dissolved and removed through ultrasonic cleaning, and the air bridge line **28** is completed.

In this manner, by placing the plurality of LEDs **1** in a two-dimensional array shape, it is possible to effectively use the substrate area and to allow a high drive voltage, in particular, driving using the commercially available power supply. Various other patterns can be employed as the pattern of the two-dimensional array. In general, the two-dimensional array pattern preferably satisfies the following conditions: (1) the shape of the LED and electrode positions are preferably identical in order to allow uniform current to flow through the LEDs and to obtain uniform light emission; (2) the sides of the LEDs are preferably straight lines in order to allow cutting of wafer to create chips; (3) the LED preferably has a planar shape similar to square in order to use a standard mount and utilize reflection from periphery to improve the light extraction efficiency; (4) a size of two electrodes (bonding pads) is preferably approximately 100 μm square and the two electrodes are preferably separated from each other; and (5) the ratio of the line and pad is preferably minimum in order to effectively use the wafer area.

These conditions are not mandatory, and it is possible, for example, to employ a planar shape of triangle as the shape of the LED. Even when the shape of the LED is a triangle, the overall shape of approximate square can be obtained by combining the triangles. Some examples of two-dimensional array patterns will now be described.

FIG. **8** shows a two-dimensional arrangement of a total of 6 LEDs **1** and FIG. **9** shows a circuit diagram of this configuration. The arrangement of FIG. **8** is basically identical to that of FIG. **6**. 6 LEDs are grouped into two groups of the same number to form LED arrays having 3 LEDs connected in series. The first LED array is arranged in a zigzag pattern with the first row having one LED and the second row having two LEDs. The LED of the first row and the rightmost LED **1** of the second row are connected in series by an air bridge line **28** and the two LEDs **1** of the second row are connected in series by an air bridge line **28**. Electrodes (pads) **32** are formed at an upper left section and a lower left section of the substrate **10**. The LED **1** of the first row is connected to the electrode **32** at the upper left section by an air bridge line and the leftmost LED **1** of the second row is connected to the electrode **32** at the lower left section. The second LED array is also arranged in a zigzag pattern and has two LEDs **1** on the first row and one LED **1** on the second row. The first row of the second LED array is formed between the first row and the second row of the first LED array and the second row of the second LED array is formed below the second row of the first LED array. The rightmost LED **1** of the first row is connected in series to the LED **1** of the second row by an air bridge line **28** and the two LEDs **1** on the first row are connected in series by an air bridge line **28**. The leftmost LED **1** of the first row is connected to the electrode **32** at the upper left section by an air bridge line **28** and the LED **1** of the second row is connected to the electrode **32** at the lower left section by an air bridge line **28**. As can be seen from FIG. **9**, in this configuration also, two LED arrays are connected between the electrodes **32** in parallel such that they are of opposite polarities. Therefore, when an AC power supply is supplied, the two LED arrays alternately emit light.

FIG. **10** shows a configuration in which a total of 14 LEDs are arranged in a two-dimensional pattern and FIG. **11** shows a circuit diagram of this configuration. 14 LEDs are grouped into two groups and the LED array has 7 LEDs connected in series. A first LED array is arranged in a zigzag pattern with the first row having 3 LEDs **1** and the second row having 4 LEDs **1**. The leftmost LED of the first row and the leftmost LED **1** of the second row are connected in series by an air bridge line **28**, 3 LEDs of the first row are connected in series by air bridge lines **28**, and 4 LEDs **1** of the second row are connected in series by air bridge lines **28**. Electrodes (pads) **32** are formed at an upper right section and a lower right section of the substrate **10**, the rightmost LED **1** of the first row is connected to the electrode **32** at the upper right section by an air bridge line and the rightmost LED **1** of the second row is connected to the electrode **32** at the lower right section. A second LED array also is arranged in a zigzag pattern with a first row having 4 LEDs **1** and a second row having 3 LEDs **1**. The first row of the second LED array is formed between the first row and the second row of the first LED array and the second row of the second LED array is formed below the second row of the first LED array. The leftmost LED **1** of the first row is connected in series to the leftmost LED **1** of the second row by an air bridge line **28**. 4 LEDs **1** on the first row are connected in series and 3 LEDs **1** on the second row are connected in series. The rightmost LED **1** on the first row is connected to the electrode **32** on the upper right section by an air bridge line **28** and the rightmost LED **1** on the second row is connected to the electrode **32** at the lower right section by an air bridge line **28**. As can be seen from FIG. **11**, in this configuration also, the two LED arrays are connected between the electrodes **32** in parallel such that they are of opposite polarities. Therefore, when an AC-power supply is supplied, the two LED arrays alternately emit light.

Characteristics common to the two-dimensional patterns of FIGS. **6**, **8**, and **10** are that the LEDs **1** have the same shape of approximate square and same size, the two electrodes (pads) also have approximate square shape and are not formed adjacent to each other (are formed separate from each other), the configuration is a combination of two LED arrays, the two LED arrays are bent and cross each other on the chip, the two LED arrays are connected between electrodes such that they are of opposite polarities, etc.

FIG. **12** shows a configuration in which LEDs having a planar shape of triangle are arranged in a two-dimensional pattern and FIG. **13** shows a circuit diagram of this configuration. In FIG. **12**, a total of 6 LEDs, LEDs **1***a*, **1***b*, **1***c*, **1***d*, **1***e*, and **1***f* are formed such that they have a planar shape of a triangle. LEDs **1***a* and **1***e* are arranged opposing each other at one side of the triangle so that the two LEDs form an approximate square and LEDs **1***b* and **1***f* are placed opposing each other, so that the two LEDs form an approximate square. The LED **1***d* and an electrode **32** oppose and are connected to each other and the LED **1***c* and an electrode **32** oppose and are connected to each other. Similar to the LEDs, the two electrodes **32** also have a planar shape of a triangle and are placed to form an approximate square. The opposing sides of the LEDs form an n electrode **24**, that is, two opposing LEDs share the n electrode **24**. Similarly, the LED and the electrode **32** are connected through the n electrode. In this arrangement also, the 6 LEDs are grouped into two groups similar to the above-described arrangements. A first LED array includes the LEDs **1***a*, **1***b*, and **1***c*. A p electrode **22** of the LED **1***a* is connected to the electrode **32** by an air bridge line **28** and an n electrode **24** of the LED **1***a* is connected to a p electrode **22** of the LED **1***b* by an air bridge line **28**. An n electrode **24** of the LED **1***b* is connected to a p electrode **22** of the LED **1***c* by an air bridge line **28**. An n electrode **24** of the LED **1***c* is connected to the electrode **32**. A second LED array includes LEDs **1***d*, **1***e*, and **1***f*. The electrode **32** is connected to a p electrode **22** of the LED **1***f* by an air bridge line **28**, an n electrode **24** of the LED **1***f* is connected to a p electrode **22** of the LED **1***e* by an air bridge line **28**, an n electrode **24** of the LED **1***e* is connected to a p electrode **22** of the LED **1***d* by an air bridge line **28**, and an n electrode **24** of the LED **1***d* is connected to the electrode **32**.

In FIG. **13**, it should also be noted that the n electrode of the LED **1***a* which is a part of the first LED array is connected to the n electrode of the LED **1***e* which is a part of the second LED array and the n electrode of the LED **1***b* which is a part of the first LED array is connected to the n electrode of the LED **1***f* which is a part of the second LED array. By sharing some of the n electrodes in the two LED arrays, it is possible to reduce the amount of circuit wiring. In addition, in this configuration also, the two LED arrays are connected between the electrodes **32** in parallel such that they are of opposite polarities. The LEDs have the same shape and the same size, and by placing the LEDs to oppose at one side and forming the electrode **32** in a triangular shape, it is possible to densely form the LEDs and electrodes to reduce the necessary area of the substrate.

FIG. **14** shows another configuration in which LEDs having a planar shape of a triangle are arranged in a two-dimensional pattern and FIG. **15** shows a circuit diagram of this configuration. In this configuration, a total of 16 LEDs, LEDs **1***a*-**1***r* are two-dimensionally formed. LEDs **1***a* and **1***j*, LEDs **1***b* and **1***k*, LEDs **1***c* and **1***m*, LEDs **1***d* and **1***n*, LEDs **1***e* and **1***p*, LEDs **1***f* and **1***q*, and LEDs **1***g* and **1***r* oppose each other at one side of the triangle. An n electrode **24** is formed common to the LEDs at the opposing side. The LED **1***i* and an electrode **32** oppose each other and the LED **1***h* and an electrode **32** oppose each other. A first LED array includes the LEDs **1***a*, **1***b*, **1***c*, **1***d*, **1***e*, **1***f*, **1***g*, and **1***h* and a second LED array includes the LEDs **1***r*, **1***q*, **1***p*, **1***n*, **1***m*, **1***k*, **1***j*, and **1***i*. An n electrode **24** of the LED **1***b* is connected to a p electrode **22** of the LED **1***c* by an air bridge line **28** and an n electrode **24** of the LED **1***e* is connected to a p electrode **22** of the LED **1***f* by an air bridge line **28**. An n electrode **24** of the LED **1***q* is connected to a p electrode **22** of the LED **1***p* by an air bridge line **28** and an n electrode of the LED **1***m* is connected to a p electrode **22** of the LED **1***k* by an air bridge line **28**. In FIG. **14** also, a crossing portion occurs similar to FIG. **12**, but short-circuiting can be avoided by the air bridge lines **28**. In this configuration also, some of the n electrodes **24** in the two LED arrays are formed as common structures in order to reduce the amount of necessary wirings. Moreover, in this configuration also, the two LED arrays are connected between the electrodes **32** in parallel so that they are of opposite polarities and the device can be AC driven. FIG. **12** shows a case of 6 LEDs and FIG. **14** shows a case of 16 LEDs. Similar two-dimensional arrangements can be achieved also with different numbers of LEDs. The present inventors have created a light emitting device in which 38 LEDs are arranged in a two-dimensional pattern.

Cases of AC drive have been described, but the structure can also be DC driven. In this case, the LED arrays are not connected between the electrodes to have opposite polarities, but rather, the LED array is connected in a forward direction along the direction of polarity of the DC power supply. By connecting a plurality of LEDs in series, it is possible to achieve a high voltage drive. Configurations for DC drive will now described.

FIG. **16** shows a configuration in which two LEDs are connected in series and FIG. **17** shows a circuit diagram of this configuration. Each LED **1** has a planar shape of a rectangle and an air bridge line **28** connects between two LEDs. An electrode **32** is formed near each LED **1** and the electrode **32** and the LED **1** form a rectangular region. In other words, the electrode **32** occupies a portion of the rectangular region and the LED **1** is formed in the other portion in the rectangular region.

FIG. **18** shows a configuration in which 4 LEDs are arranged in a two-dimensional pattern and FIG. **19** shows a circuit diagram of this configuration. In this configuration, each of the LEDs **1** of FIG. **16** is divided into two LEDS and the two LEDs are connected in parallel. This configuration can also be described as two LED arrays each of which is made of two LEDs connected in parallel in the forward direction. The LEDs **1***a* and **1***b* form one LED array and the LEDs **1***c* and **1***d* form another LED array. The LEDs **1***a* and **1***c* share a p electrode **22** and an n electrode **24** and LEDs **1***b* and **1***d* also share a p electrode **22** and an n electrode **24**. With this configuration, there is an advantage in that the current is more uniform compared to the configuration of FIG. **16**.

FIG. **20** shows a configuration in which three LEDs are arranged in a two-dimensional pattern and FIG. **21** shows a circuit diagram of this configuration. LEDs **1***a*, **1***b*, and **1***c* do not have the same shape and an electrode **32** is formed in a portion of the LED **1***a*. An n electrode **24** of the LED **1***a* is connected to a p electrode of the LED **1***b* by an air bridge line **28** striding over the LED **1***b*. By devising the shape and arrangement of the LEDs, even with 3 LEDs, the overall outer shape of the light emitting device (chip) can be formed in an approximate square.

FIG. **22** shows a configuration in which a total of 6 LEDs are arranged in a two-dimensional pattern and FIG. **23**

shows a circuit diagram of this configuration. The LEDs **1***a*-**1***f* have the same shape and same size and are, connected in series. The LEDs **1***a*-**1***c* are placed on a straight line and the LEDs **1***d*-**1***f* are placed on another straight line. The LEDs **1***c* and **1***d* are connected by an air bridge line **28**. In this configuration also, the overall shape of the chip can be made approximate square.

FIG. **24** shows a configuration in which a total of 5 LEDs are arranged in a two-dimensional pattern and FIG. **25** shows a circuit diagram of this configuration. LEDs **1***a*-**1***e* have the same shape (rectangle) and the same size. In this configuration also, the overall shape can be made approximate square.

A preferred embodiment of the present invention has been described. The present invention is not limited to the preferred embodiment and various modifications can be made. In particular, the pattern when a plurality of light emitting elements (LED or the like) are arranged in a two-dimensional pattern may be patterns other than the ones described above. In this case, it is preferable to share electrodes between adjacent light emitting elements to reduce the amount of wiring, form the overall shape in square or rectangle, connect a plurality of groups of light emitting element arrays between electrodes in parallel, arrange the plurality of light emitting element arrays in opposite polarities when AC driven, combine the plurality of groups of light emitting element arrays by bending the light emitting element arrays in a zigzag pattern, etc.

FIGS. **26**-**31** exemplify some of these alternative configurations. FIG. **26** shows a two-dimensional arrangement in an example employing AC drive of a total of 40 LEDs. FIG. **27** is a circuit diagram of this configuration. The configuration of FIG. **26** differs from that of FIG. **6** in that some of the two groups of LED arrays share the n electrode **24** (refer to FIG. **5**). For example, an n electrode **24** of a second LED from the right of the first row of the first LED array (shown in the figure by .alpha.) is shared as the n electrode **24** of the rightmost LED of the first row of the second LED array (shown in the figure by .beta.). Air bridge lines **28** at the ends of the LED arrays (shown in the figure by .gamma.) are commonly formed without crossing.

FIG. **28** shows a two-dimensional arrangement in a configuration employing AC drive and a total of 14 LEDs. FIG. **29** is a circuit diagram of this configuration. The configuration of FIG. **28** differs from that of FIG. **10** in that some of the two groups of LED arrays share the n electrode **24**. For example, an n electrode **24** of the leftmost LED on a first row of a first LED array (shown in the FIG. by .alpha.) is shared as an n electrode **24** of an LED located second from the right on a first row of a second LED array (shown in the figure by .beta.). Air bridge lines **28** at the ends (shown in the figure by .gamma.) are commonly formed.

FIG. **30** shows a two-dimensional arrangement in a configuration employing AC drive and a total of 6 LEDs. FIG. **31** is a circuit diagram of this configuration. In this configuration also, air bridge lines **28** at the ends (.gamma. portion) are commonly formed. It can be considered that in this configuration also, an n electrode **24** in the first LED array and an n electrode **24** of the second LED array are shared.

What is claimed is:

1. A light-emitting device comprising:
- a growth substrate;
- a GaN-based light-emitting element monolithically formed on the growth substrate;
- an n-electrode and a p-electrode disposed on the GaN-based light emitting element;
- an electrode pad for a power supply, the electrode pad being spaced apart from the light-emitting element and disposed on the growth substrate; and
- a wiring electrically connecting the electrode pad and the light emitting element,
- wherein the light-emitting element comprises a recessed area, and at least a portion of the electrode pad is disposed in the recessed area of the light-emitting element.

2. The light-emitting device of claim **1**, wherein the electrode pad is disposed on a first region of the growth substrate where light is not generated.

3. The light-emitting device of claim **1**, wherein the GaN-based light emitting element comprises:
- a n-type semiconductor layer;
- an active layer; and
- a p-type semiconductor layer.

4. The light-emitting device of claim **3**, wherein the electrode pad is electrically connected to the n-type semiconductor layer or the p-type semiconductor layer through the wiring.

5. The light-emitting device of claim **1**, wherein the overall shape of the light-emitting device is rectangular.

6. The light-emitting device of claim **1**, wherein the overall shape of the light-emitting device is square.

7. The light-emitting device of claim **5**, wherein the electrode pad comprises a rectangular shape.

8. The light-emitting device of claim **6**, wherein the electrode pad comprises a square shape.

9. The light-emitting device of claim **1**, wherein the GaN-based light emitting element comprises a polygonal shape.

10. The light-emitting device of claim **1**, wherein:
- the GaN-based light emitting element comprises a polygonal shape with more than four sides and a recessed area where a first pair of sides meet at a substantially right angle; and
- the electrode pad is disposed substantially in the recessed area.

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